AAPG Datapages/Search and Discovery Article #90235 © 2015 AAPG Asia Pacific Region, Geoscience Technology Workshop, Modern Depositional Systems as Analogues for Petroleum Reservoirs, April 21-22, 2015, Wellington, New Zealand

Reservoir Characterization of Tidally-Influenced Reservoirs - Analogues for Exploration and Development

Dale Leckie[1]

[1]Department of Geoscience, University of Calgary, Calgary, Alberta, Canada

Abstract

Modern fluvial investigations and models generally do not take into account tidal influence, nor do studies of the coastal zone commonly penetrate landward 50 to 100 km or more to study the tidal-fluvial transition. Consequently, the identification of sedimentary sequences and facies relationships that are characteristic of the fluvial to marine transition is still in their infancy. This transitional environment is affected by an interaction of fluvial, tidal and wind-wave processes that vary daily, monthly and seasonally. The preserved sedimentary response is different from that of strictly fluvial dominated or marine-dominated estuarine settings. This tidal-fluvial environment is characterized by tremendous lithological heterogeneity that occurs on multiple scales. Yet some of the largest hydrocarbon accumulations on earth occur in these transitional deposits.

The Cretaceous Athabasca oil sands in western Canada are the second largest hydrocarbon resource on earth. Most of that resource is located in the deposits of the McMurray Formation, in multi-storey, tidally influenced, meandering river point bars having highly variable lithology and morphology. Because of the immense economic value of that resource, there exists an very large and diverse data set that includes extremely high-resolution seismic slices and cross sections, detailed core measurements, and wire line and image logs.

This talk presents a series of vignettes illustrating the various depositional styles and reservoir types of point bars found in the Cretaceous Athabasca oil sands. Sedimentological, ichnological associations and palynological recovery indicates that deposition occurred in a zone of tidal-fluvial transition; tidal indicators are rare to common. Yet, geomorphologically, the depositional environment appears to be fluvial, perhaps on a scale compared to the Mississippi River. Seismic time slice imagery shows laterally accreting point bars, downstream migrating point bars, abandoned mud-filled channels and counter point bars.

The seismic time slice image shown in Figure 1 has all the characteristics of fluvial deposits deposited landward of the backwater limit. However, the sediments are characterized by common occurrences of dinoflagellates having brackish water affinities and brackish-water bioturbation forms indicating deposition seaward of the backwater limit, at least on a seasonal basis.

The point bars of the McMurray Formation were deposited within a highly dynamic and migratory, low accommodation depositional system. Fluctuating relative sea level resulted in multiple incised valley systems. Subsequent valley fill resulted in a vertical stacking pattern of multiple depositional units or storeys.

The high-resolution seismic imagery shows that the rivers that deposited these point bars had variable sinuosity (1.6 to 2.5). The point bars migrated both by lateral accretion and by downstream translation. Core, log and seismic data show single channel deposits or storeys up to 48

m thick. The rivers, as indicated by well-preserved and imaged mud plugs were up to 600 m wide. Sand grain size is generally fine grained, although lower channels and channel bases may reach pebble size. Facies relationships, depositional elements and paleontology (ichnology and palynology) variably suggest diurnal, spring to neap cyclicity and seasonality effects on the sediments.

Generally, there is minimal evidence of levees or conventional overbank deposits. Roots and paleosols are not common; where the latter do occur, they tend to be well developed and associated with the interfluves of incised valleys. Non-reservoir muds occur as continuous to discontinuous, likely seasonally deposited mudstone layers within inclined heterolithic stratification (IHS) packages; thinner centimeter-scale muds associated with spring to neap cyclicity; and millimeter-scale slack water deposits. Channel bottom muds may be fluid in origin. Abandoned channel mud plugs associated with chute and neck cutoffs are an integral part of the deposition system as are alternating, low angle IHS. These muds may act as barrier or baffles during hydrocarbon production.

Erosional surfaces, found at the base and within point bar successions, may be the result of channel readjustment associated with high-energy flood events or other perturbations within the system. Elsewhere they are the result of avulsion and migration processes. In these tidally influenced point bars, sand concentrations seem to be concentrated at various positions in the point bars. Downstream fining is common; counter point bars are silty; some point bars are muddier at their apex.

Several point bar morphological elements are observed from the data sets. Sand-dominated side bars are deposited along the inner edge of, but detached from, the point bar. Preservation of the side bar is enhanced by channel abandonment, whereby the side bar is draped by and onlapped by silts of the mud plug. Counter point bars, characterized by high silt content, occur downstream of sandy point bars. These counter point bars are most easily identified morphologically and by their relationship to point bars using seismic imagery. Elsewhere, abandoned, migratory point bars become re-occupied through the process of chute-channel capture. Upon subsequent abandonment, the chute channel then becomes mud-filled. In rare cases, channels filled with reservoir quality sand, rather than mud, upon abandonment; the mechanism for this type of deposition is not well understood. The depositional fabric in these features appears to be dominated by unidirectional dune-scale bed forms preserving the direction of paleoflow.

Mud clast breccias are ubiquitous in the McMurray Formation. Clasts are well rounded to angular and from centimeter to metre in diameter within beds of variable thickness. The breccias typically have an oil saturated fine-grained sand matrix, although in some instances, this matrix is absent. The breccias are the result of bank collapse, erosion of mud layers on point bar surfaces and possibly on chute-channel surfaces. Breccia beds are highly variable and are difficult to resolve seismically.

What does the oil industry require to better understand the tidally-influenced point bar reservoirs? As already noted, existing fluvial studies and models do not take into account tidal influence, nor do those studying the coastal zone commonly penetrate landward 50 to 100 km or more to study the tidal-fluvial transition. What the industry needs in order to more efficiently produce this bitumen resource is a better understanding of the mixing of tidal and fluvial processes, in addition to the importance of seasonality and longer-term climate cyclicity in this setting. Currently, there is not a solid comprehension of the fluid and sediment dynamics in tidal-fluvial transitional systems. We are still looking for appropriate analogs to add to databases. What are the most prevalent mixed tidal and fluvial depositional processes and which impart the strongest control on sediment variability, both laterally and vertically?

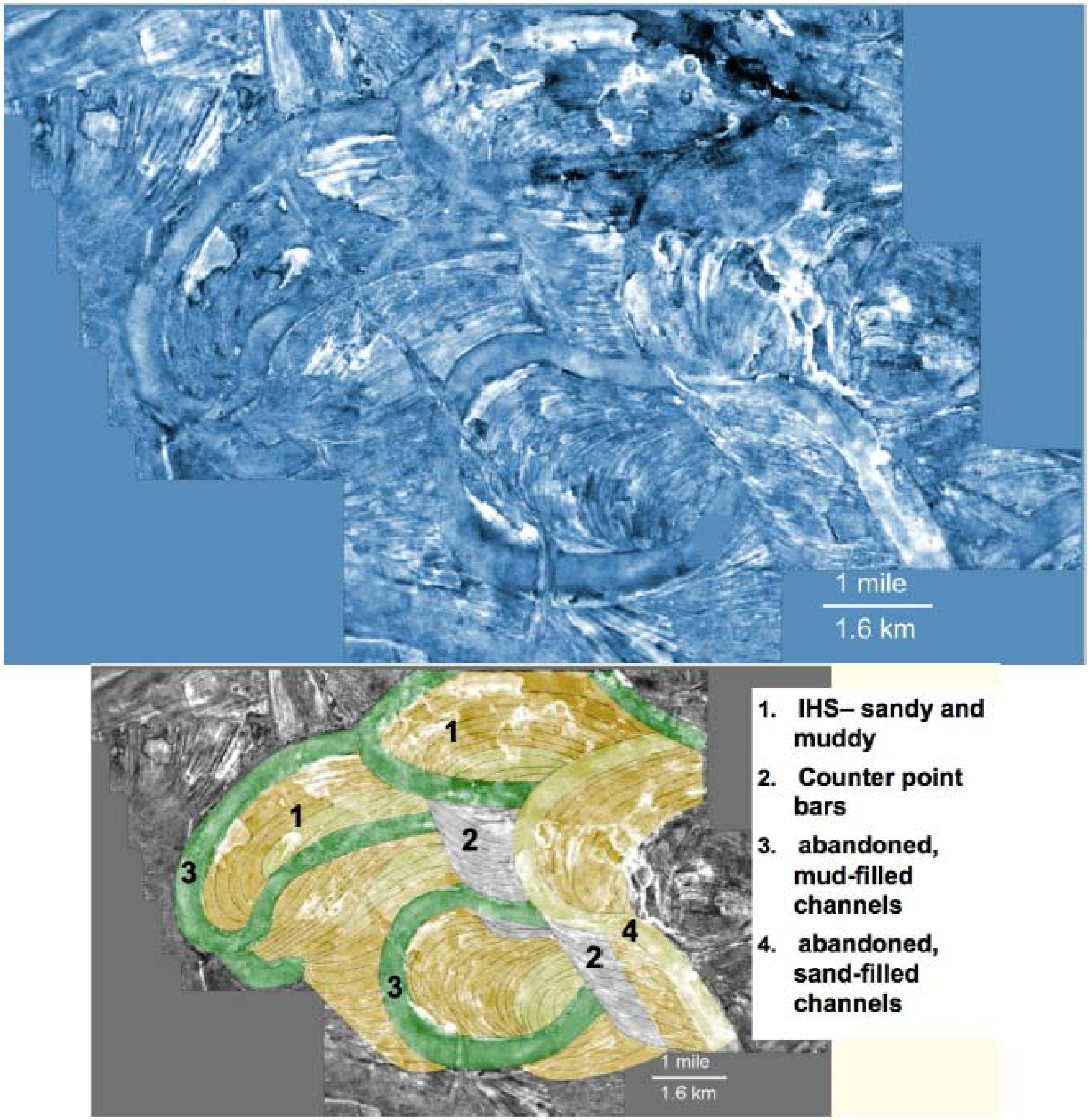

Figure 1. Seismic time slice and interpretation of architectural elements from 8 ms below the top of the McMurray Formation. These sediments were deposited within the tidally influenced fluvial transition zone. The sediments are bioturbated with brackish-water indicators and contain dinoflagellates also of brackish water origin. Note the scale. The width of the mud-filled channels indicates rivers 400 -600 m wide, with resulting point bar deposits several kilometers in size.